

A search for new variable stars using digitized Moscow collection plates

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Abstract

By digitizing astronomical photographic plates one may extract full information stored on them, something that could not be practically achieved with classical analogue methods. We are developing algorithms for variable objects search using digitized photographic images and apply them to 30 cm ($10^\circ \times 10^\circ$ field of view) plates obtained with the 40 cm astrograph in 1940–90s and digitized with a flatbed scanner. Having more than 100 such plates per field, we conduct a census of high-amplitude ($> 0.3m$) variable stars changing their brightness in the range $13 < m < 17$ on timescales from hours to years in selected sky regions. This effort led to discovery of ~ 1000 new variable stars. We estimate that $1.2 \pm 0.1\%$ of all stars show easily-detectable light variations; $0.7 \pm 0.1\%$ of the stars are eclipsing binaries ($64 \pm 4\%$ of them are EA type, $22 \pm 2\%$ are EW type and $14 \pm 2\%$ are EB type); $0.3 \pm 0.1\%$ of the stars are red variable giants and supergiants of M, SR and L types.

Keywords: variable stars, photographic photometry

1 Introduction

Historical sky photographs present a record of positions and brightness of astronomical objects. They are used to study behaviour of objects as diverse as Solar system bodies [1, 2], binary stars [3, 4], and active galactic nuclei [5, 6] on timescales not accessible with CCD imaging data. A few authors used digitized photographic plates to identify previously unknown variable objects [7, 8, 9, 10].

The Moscow collection contains about 60000 photographic plates (mostly direct sky images) dating back to 1895. The most important part of the collection, known as the “A” series, are 22300 plates taken in 1948–1996 with the 40 cm astrograph [11]. These are blue-sensitive 30 cm by 30 cm plates covering $10^\circ \times 10^\circ$ field on the sky down to the limiting magnitude of $B \sim 17.5$. The typical exposure time is 45 min.

The original aim of obtaining the “A” series plates was to study variable stars. We decided to extend this work using modern image analysis techniques. The first tests confirmed that it is possible to find variable objects using small sections of plates digitized with a flatbed scanner [12, 13, 14, 15] and we went ahead to process a series of full-sized $10^\circ \times 10^\circ$ plates [16, 17]. Below we describe the current state of the project.

For the original tests we used a pair of CREO/Kodak EverSmart Supreme II scanners operating at 2540 dpi resolution ($1''/2/\text{pix}$). While showing good photometric performance (typically $< 0.1m$ accuracy of an individual measurement), the scanners were suffering from problems common to many flatbed scanners including poor out-of-the-box astrometric performance caused by irregular motion of the scanner drive (Fig. 1) and stitches between image parts digitized during different passes of the scanning array over a photographic plate. It takes about 40 minutes to digitize a half of the 30 cm plate with the Supreme II scanner. The time it takes to clean a plate and manually place it into a scanner is small compared to the scanning time. The original Supreme II scanners were recently replaced by the new Epson Expression 11000XL which provides a factor of two increase in scanning speed operating at 2400 dpi resolution ($1''/4/\text{pix}$). The Supreme II and Expression 11000XL scanners provide comparable results in terms of photometric and astrometric accuracy. Still, because the scanning process is so slow, we consider it to be more of a technology development tool and an opportunity to investigate a few individual fields rather than a practical way to digitize all the Moscow plate collection in reasonable time.

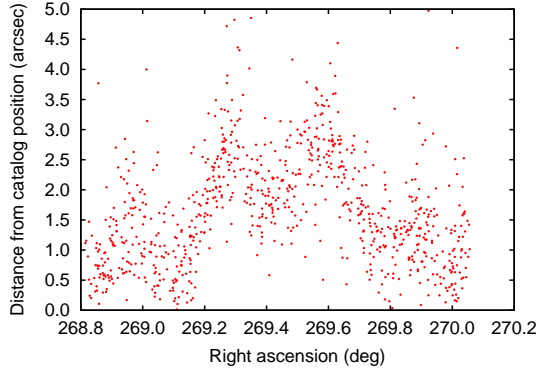


Figure 1: Deviation from the catalog position as a function of R.A. Plate solution with the 2nd order polynomial correction is applied for this $1^{\circ}3 \times 1^{\circ}3$ field digitized with the Expression 11000XL scanner.

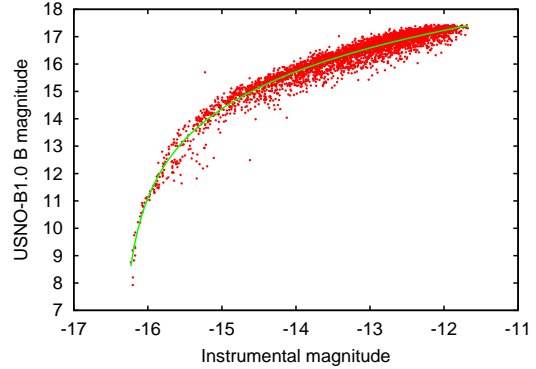


Figure 2: The magnitude calibration curve for the same field as Fig. 1. Points represent stars matched with the USNO-B1.0 catalog.

2 Plate digitization and data reduction

The plates are digitized with 48 bit color depth (16 bit/color channel) and saved into a TIFF format using a control software supplied with a scanner. TIFF is the only format capable of preserving such color depth that is supported by the control software of both scanner types. This format has a built-in limitation that a file cannot be larger than 2^{32} bytes (4 Gb) corresponding to a $\sim 9400 \times 9400$ pix image at 48 bit color depth. This means that a 30 cm plate cannot be scanned into a single file, so in practice a plate is scanned into two files with a small overlap between the two images. This does not pose a problem for the subsequent analysis.

The TIFF images are converted into FITS format using the `tiff2fits`¹ code. Data from only the green channel are used to write a monochrome FITS image. The negative images are inverted at this stage to have white stars on dark background. Large images are cut into pieces of about $1^{\circ} \times 1^{\circ}$ so sensitivity variation caused by vignetting and other aberrations in the astrograph's optics as well as atmospheric transparency variations can be approximated as a linear function of an object's position on a small image. Since plates that belong to the same “field” may have offsets of more than 1° between their centers, a star is used as a reference point for cutting to ensure that the same sky area is covered by small images resulting from cutting scans of different plates.

Each series of small images is processed independently using the `VaST`² variability search software [18]. `VaST` is using `SExtractor`³ [19] to perform object detection and aperture photometry (the aperture size is determined individually for each image to compensate for seeing variations) and performs cross-identification of stars detected on the images producing lightcurves of all detected stars as an output. The circular aperture size is optimized for measuring stars with $B > 13$. The images are plate-solved using the `Astrometry.net`⁴ software [20, 21] and the internal magnitude scale is calibrated by matching the detected stars to the USNO-B1.0 catalog [22]. Following [23] we use the relation of the form $m_1 = a_0 \times \log_{10} (10^{a_1 \times (m_2 - a_2)} + 1) + a_3$ proposed by [24] to match catalog B (m_2) magnitudes to the measured aperture magnitudes (m_1) through the fitted coefficients a_0, a_1, a_2 , and a_3 (Fig. 2). This relation is also utilized to match instrumental magnitude scales of individual frames before performing absolute calibration. The obtained lightcurves are used to search for variable stars using an RMS–magnitude plot and period search techniques [17].

¹<http://scan.sai.msu.ru/pub/software/tiff2fits/>

²<http://scan.sai.msu.ru/vast/>

³<http://www.astromatic.net/software/sextractor>

⁴<http://astrometry.net/>

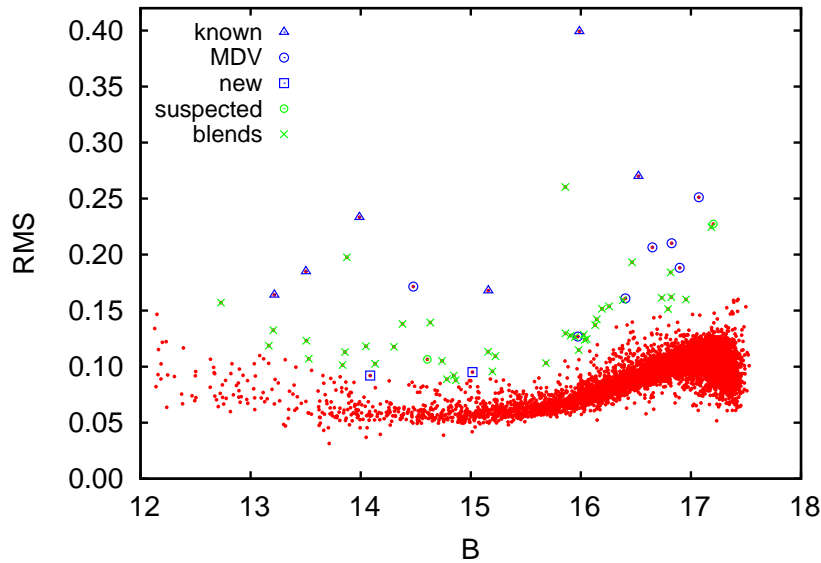


Figure 3: Lightcurve RMS as a function of mean magnitude.

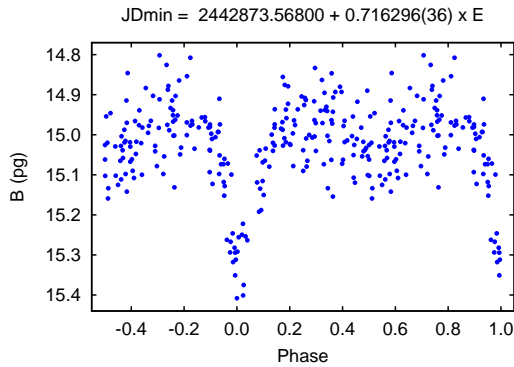


Figure 4: Lightcurve of B1.0 0953-0319502.

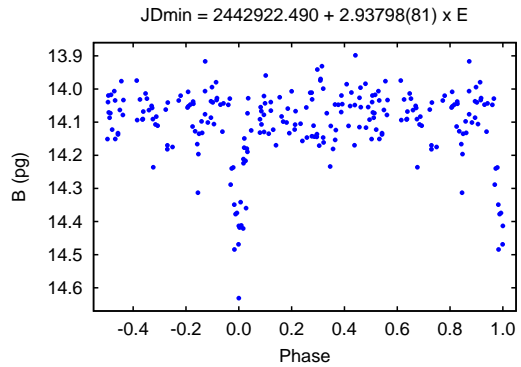


Figure 5: Lightcurve of B1.0 0944-0313124.

3 Results

Fig. 3 presents the RMS–magnitude plot for the test field digitized with our new Expression 11000XL scanner. The plot marks previously known variable stars in this field (“known”), variables identified by [16] (“MDV”), “suspected” variables, and constant stars with photometry corrupted by a close neighbor (“blends”). Two new Algol-type binaries were identified while processing the test data (marked as “new”), their lightcurves are presented in Fig. 4 and 5.

We applied this variable stars search technique to three $10^\circ \times 10^\circ$ fields centered at 66 Oph (254 plates exposed in 1976–1995), BD+60°636 (182 plates, 1949–1989), and β Cas (391 plates, 1964–1994). Processing of 66 Oph and BD+60°636 fields resulted in discovery of 557 previously unknown variable stars including 6 Cepheids (Type I and II), 147 RR Lyrae type variables, 12 High-amplitude δ Scuti stars (HADS), 168 red semiregular and irregular (types SR and L) variables, 222 eclipsing binaries, 2 BY Dra type stars. Preliminary processing of 50 % of the β Cas field (the most well-sampled of the three studied fields) resulted in detection of 604 variable stars (454 of them new) among ~ 51000 stars in the magnitude range accessible for our variability search. We estimate that $1.2 \pm 0.1\%$ of the stars show easily-detectable (amplitude $> 0.3m$) light variations; $0.7 \pm 0.1\%$ of the stars are eclipsing binaries ($64 \pm 4\%$ of them are EA type, $22 \pm 2\%$ are EW type and $14 \pm 2\%$ are EB type); $0.3 \pm 0.1\%$ of the stars are red variable giants and supergiants of M, SR and L types. The fraction of pulsating variable stars of all types is expected to be a

strong function of the Galactic latitude and deserves a more detailed investigation. The errors are estimated from the Poisson statistics and cannot account for any systematic effects remaining in our search.

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